Nutrient Management Behavior on Wisconsin Dairy Farms

J. M. Powell,* D. B. Jackson-Smith, D. F. McCrory, H. Saam, and M. Mariola

ABSTRACT

Nutrient management plans for livestock operations should account for rates and timing of manure application to cropland, as well as how manure is integrated with other nutrient sources. Little is known, however, about actual nutrient management behavior of farmers, and what changes may be needed for farmers to adhere to nutrient management regulations. Detailed records were kept on fertilizer, manure, and legume N and P applications on 33 representative Wisconsin dairy farms during the period October 2003 through September 2004. Average available N applications ranged from 118 to 200 kg ha^{-1} of which 40% was derived from fertilizer, 30% from manure and 30% from previous legume. On a regional basis, the following percentages of corn (*Zea mays* L.) area fell within available N application categories of 0, 1 to 80, 81 to 160, 161 to 240 and >240 kg ha^{-1}, respectively: in the Northeast (NE) region, <1, 26, 33, 21, and 19% of the total corn area surveyed (504 ha); in the South–Central (SC) region, <1, 39, 41, 14, and 5% of the corn area (576 ha); and in the Southwest (SW) region, 0, 31, 45, 14, and 10% of the corn area (180 ha). Average available P applications ranged from 16 to 18 kg ha^{-1}, of which 65% came from manure and 35% from fertilizer. On a regional basis, the following percentages of surveyed cropland area fell within available P application categories of 0, 1 to 24, 25 to 48, 49 to 72 and >72 kg ha^{-1}, respectively: in the NE region, 30, 50, 15, 4, and 1% of the cropland area (1340 ha); in the SC region, 23, 54, 17, 5, and 1% of the cropland area (1168 ha); and in the SW region, 41, 48, 8, 1, and 2% of the cropland area (542 ha). Of the total cropland area (ha) across all regions that received manure during winter, 7 to 25% were within regulated surface water buffer zones. In the NE, SC, and SW regions, 100, 83, and 63% of winter-spread cropland area received available P application rates <24 kg ha^{-1}, the 1-yr crop P replacement ceiling set by State regulations. Regional differences in nutrient management behavior due to topography, soils and other factors should be used to better target efforts aimed at improving fertilizer-manure-legume management on Wisconsin dairy farms.

Approximately two-thirds of Wisconsin's dairy farms are self-sufficient in grain and forage production and have more than adequate cropland area to spread manure according to newly introduced P-based nutrient management standards (Powell et al., 2002; Saam et al., 2005; DATCP, 2006). Many dairy farmers, however, use only a portion of their total cropland area for manure spreading. On average, 23, 30, and 44% of the total cropland area receives manure annually in the NE, SC and SW regions, respectively (Saam et al., 2005). Differences in manure spreading on Wisconsin dairy farms have been linked to many factors: including the amount of manure actually collected (Powell et al., 2005), the presence of manure storage, labor availability and machinery capacity for manure spreading, variations in the number of days manure can be spread given regional differences in weather and soil conditions, and distances between where manure is produced and fields where manure can be applied (Nowak et al., 1997). Manure spreading is also related to land ownership; as the percentage owned cropland operated by a farmer increases, so does percentage of operated cropland that receives manure (Saam et al., 2005).

Livestock operations are currently required to have nutrient management plans to qualify for most federal and state cost-sharing programs aimed at water quality improvements. Nutrient management plans need to account for all nutrient applications to cropland, including fertilizer, manure, previous legume crops grown in rotation with cereals, and other organic amendments. Whereas various tools are available to estimate dairy manure production (e.g., Nennich et al., 2005) and collection (Powell et al., 2005), little information is available on when, where and how much manure is actually applied to cropland; how farmers blend nutrients from various sources; and how well prevailing farmer nutrient management behavior conforms to nutrient management standards.

The "On-Farmers' Ground" (OFG) study was established in 2002 with 54 representative Wisconsin dairy farms to evaluate possible impacts of farm size, operational features, climate, and soils on overall nutrient use (NPM, 2006). The first analysis of the OFG study examined manure collection (Powell et al., 2005). The second analysis validated feed and manure data, and concluded that data collected by farmers and the research team provided accurate information on a whole-farm basis (Powell et al., 2006). The objective of the present analysis was to evaluate nutrient management behavior on a field-by-field basis by determining when, where and how much manure was land applied; how much N and P was applied to cropland as fertilizer and legume N credits; and evaluate if manure-spreading practices conformed to Wisconsin 590 Nutrient Management Standards (DATCP, 2006). An additional objective was to evaluate possible relationships between farmer nutrient management behavior and operational characteristics of farms, such as farm size, livestock density, manure collection,

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Published in Agron. J. 99:211–219 (2007).
Integrated Agricultural Systems
doi:10.2134/agronj2006.0116

Abbreviations: CAFOs: concentrated animal feeding operations; DM, dry matter; NE, Northeast region of Wisconsin; OFG, "On-Farmers' Ground" study; OM, organic matter; SC, South-Central region of Wisconsin; SWQMA, surface water quality management areas; SW, Southwest region of Wisconsin.

and spatial arrangement of barns (where manure was produced) and fields (where manure was applied).

MATERIALS AND METHODS

The On-Farm Survey

A three-step, stratified random sampling procedure was used to select 54 farms that represented the range of farm sizes, livestock densities and manure recycling capacities typical of the Wisconsin Dairy Industry (Powell et al., 2005; Saam et al., 2005). Briefly, a subset of 270 dairy farms was selected from a representative pool of 804 respondents to the 1999 Wisconsin Dairy Farm Survey (Buttel et al., 1999). Second, farms were stratified into one of three partial P balance (crop P–manure P balances; Saam et al., 2005) categories. Third, farms were randomly selected from each of the three P balance categories. Farmers were contacted by phone and asked to participate in the study. Phone calls were made until 18 farms (6 within each P balance stratum) from each region agreed to participate in the study. This stratified random sampling approach provided a total of 54 farms distributed across the major soil types, watersheds of impaired waterbodies, and dairy counties of Wisconsin (Powell et al., 2005). Of the original 54 farms, five went out of business during the 1st year of the study. Additional farmer attrition, incomplete data and other factors provided valid fertilizer, manure and legume nutrient management information on 33 of the original 54 farms. These 33 farms had herd size and cropping pattern characteristics (Table 1) similar to the general dairy farm populations of these regions (Jackson-Smith et al., 2000).

Farm selection was based on the hypothesis that regional differences in soil texture, land tenure, and development pressures might affect manure-spreading behaviors. The SW region, for example, is characterized by more coarsely textured silt loam soils (Hole, 1976) that have relatively high permeability and drier field conditions in the spring and fall than other regions of Wisconsin (McCrory et al., 2004). By contrast, the NE is characterized by more finely textured and less permeable clayey and red loam soils. The SC region has soil textures and manure spreading days intermediate to the NE and SW. Differences in land tenure, or the percentage of operated land that is owned, was thought to also influence manure spreading behaviors. Farmers in the SW tend to rent smaller areas and thus own a greater proportion of their total operated land area than farmers in the SC and NE regions (Saam et al., 2005). Greater areas of rented land may contribute to a decreased percentage of cropland that receives manure. Perhaps more importantly, the travel distance between where dairy cattle are housed (and where the manure is produced) and the location of fields may greatly affect whether a field receives manure. Because there is a higher level of nonfarm development pressures in the NE, farmers in this region may have greater difficulty finding access to close-by rented cropland for manure application, compared to the other regions having lower development pressure.

A structured survey instrument was used to collect information on farm characteristics and practices, including livestock inventories and cropping practices, field histories, and basic operation characteristics (ownership, management, labor, scale, use of key technologies). During the initial 2- to 3-h interview on each farm, aerial photographs were used to record farm and field boundaries, which were then coded and digitized for use throughout the study. For each field on each farm, crop rotations were defined and general questions were posed related to fertilizer (type and amount applied), manure and legume management. Three to four additional farm visits (4–5 total visits per farm) were conducted during subsequent months to track information regarding cropping cycles, changes to herd size, changes to number or arrangement of fields; collect manure logs and samples; review data collected with farmers; etc. Phone calls to farmers and their crop consultants were made as needed to verify collected data, solicit new information, and investigate seeming discrepancies.

Manure Management

The collection of field-level data on fertilizer and manure management covered the period October 2003 to September 2004, corresponding to farmers' Fall (Oct.–Nov.), Winter (Dec.–Mar.), Spring (Apr.–May) and Summer (June–Sept.) manure-spreading periods. A manure record book was developed to track when, where, how much, and what type of manure was spread on a daily basis. Farmers were asked to record manure type (semisolid, liquid, bedded pack), spreader type, fields receiving the manure, and the relative fullness of each spreader on departure for spreading. Manufacturer information on spreader capacities was used to estimate manure mass spread. Labeled containers were provided and farmers were instructed on collection of representative manure samples (Peters et al., 2003). Semisolid manure samples of approximately 500 g were taken every 8 wk and liquid manure

Table 1. Regional and statewide dairy herd and cropland characteristics of Wisconsin dairy farms.

Farm component	Regions (this study) NE (n = 12 farms)	SC (n = 12 farms)	SW (n = 9 farms)	All (n = 33 farms)	Statewide avg.† (n = 717)
Herd size	lactating + dry cows farm^{-1}				
	84‡ (43–215)	70 (22–175)	46 (16–85)	69 (22–215)	83 (NA)¶
Herd size distribution	% of n farms				
1–49 cows	8	33	56	30	37
50–99 cows	76	50	44	58	43
100–199 cows	8	17	0	9	13
200+ cows	8	0	0	3	7
Operated land	ha farm^{-1}				
Total	124 (38–321)	113 (47–296)	115 (28–351)	118 (28–351)	145 (NA)
Corn	40 (16–106)	44 (15–127)	36 (0–165)	40 (0–165)	(NA)
Alfalfa (*Medicago sativa* L.)	52 (15–125)	35 (14–96)	57 (15–186)	47 (14–186)	(NA)
Soybean [*Glycine max* (L.) Merr.]	12 (0–44)	10 (0–91)	2 (0–11)	8 (0–91)	(NA)
Small grains	7 (0–34)	6 (0–23)	2 (0–10)	5 (0–34)	(NA)
Pasture	3 (0–13)	7 (0–16)	15 (0–52)	8 (0–52)	(NA)

† PATS, 2004.
‡ Mean (range in parentheses).
¶ Not available.

samples of the same weight were taken periodically during the period when farmers removed and land-spread manure from storage. Farmers kept manure samples frozen until pick-up by the research team, and samples remained frozen until analyzed. Manure subsamples were acidified (6 mL 0.35 *M* H_2SO_4 per 20 g wet manure), freeze-dried, and ground to pass a 2-mm screen. Total N content of manure samples was determined by combustion assay (Leco FP-2000 nitrogen analyzer, Leco Instruments, St Joseph, MI). Ground manure subsamples were oven-dried (100°C, 24 h) for dry matter (DM) determination, and ashed in a muffle furnace (500°C, 24 h) for organic matter (OM) determination. Ash was dissolved in HCl, and total P in this solution was determined using direct current plasma emission spectroscopy. The amount of manure N and P land-applied was calculated by multiplying manure mass in a spreader by the DM, N and P content of manure samples corresponding to the spreading period.

Maps depicting annual N and P applications from fertilizers, manure and legumes, and seasonal manure N and P applications were developed. During the mapping process, Euclidian (straight-line) distances (km) between the barn and the approximate center of each field were determined for each farm. This information was used to evaluate possible regional and seasonal differences in distances traveled by farmers with their manure spreaders. Cropland areas (ha) in each N and P application category were determined using ArcView software (ESRI, Redlands, CA).

State Nutrient Management Guidelines and Input Assumptions

Wisconsin's Code 590 Nutrient Management Standard (DATCP, 2006) states that available N applications from all sources (e.g., fertilizers, manures, legumes) shall not exceed the annual N requirement of the following cereal crop. Our most detailed analysis of N management pertains to corn production, for cornfields received the majority of applications of fertilizer N, manure and legume credits. For this analysis, the following assumptions were made (Bundy et al., 1994; Kelling et al., 1998): 1st year alfalfa N credits of 134 and 78 kg ha^{-1} for medium/fine and sandy textured soils, respectively; N credit of 45 kg ha^{-1} for soybeans except on sandy soils (no credit); 1st year manure N availability of 35%; and fertilizer N availability of 100%. Cornfield areas (ha) on each farm were assigned to one of five available N application (kg ha^{-1}) categories: 0; 1 to 80, a range below annual corn N requirements; 81 to 160, slightly lower to within the range of annual corn N requirements; 161 to 240, slightly above annual corn N requirements; and >240, levels that would exceed annual corn N requirements. Wisconsin's Code 590 Nutrient Management Standard (DATCP, 2006) also states that annual P applications (kg ha^{-1}) may be combined into a single application that does not exceed the total P requirement for the rotation, but this high single application would not be permitted on frozen ground. When frozen or snow-covered soils prevent effective incorporation at the time of application, but the nutrient application is allowed, nutrients cannot be applied within the Surface Water Quality Management Area (SWQMA, the area within 91 m of and draining to perennial streams, and within 304 m of lakes or ponds). Manure application also may not exceed the P removal (kg ha^{-1}) of the following growing season's crop when applying manure. Using the same procedure as available N, the following assumptions were made (Kelling et al., 1998): 1st year manure P availability of 60%, and fertilizer P availability of 100%. Field areas (ha) on each farm (all crops, including corn) were assigned to one of five available P application categories (kg ha^{-1}): 0; 1 to 24, the upper range of which would encompass the 1-yr crop P requirement; 25 to 48, the mid- to upper range of which would encompass a 2-yr crop P requirement; 49 to 72, which would encompass a 3-yr crop P removal; and >72, which would exceed 3-yr crop P removal (Powell et al., 2002).

As part of the analysis of farmer adherence to winter manure spreading regulations, the amount (kg ha^{-1}) and location of manure P applications were determined for the months of December through March, the period in Wisconsin when soil surfaces are most likely to be frozen. SWQMA areas (ha) were delineated around water bodies, and the relative cropland areas (ha) that received manure within and outside SWQMAs during this winter period were determined using ArcView software.

Statistics

Means, Confidence Intervals (95%) and ranges were used to depict regional differences and variability in data related to herd size and cropping characteristics; field types, sizes and distances; nutrient management behavior including available N and P application categories; and seasonal manure-spreading practices. Because of possible non-normal variances associated with percentages, percentage land areas in available N and P application categories, etc., were transformed into "tpercents" (SAS Institute, 1990) before data analyses. The general linear model and the protected least significant difference (LSD) test were used to determine regional differences ($P < 0.05$) in patterns of manure land-spreading behavior (SAS Institute, 1990).

RESULTS

Dairy Herd Size and Cropping Systems

On average, the study farms ($n = 33$) had somewhat smaller dairy herd sizes and cropland areas than a larger sample ($n = 717$) of Wisconsin dairy farms (Table 1). Of the original 54 dairy farms, the 19 farms not included in the present analyses had somewhat larger herd sizes and cropland areas. The 33 farms in the present analyses (Table 1) still provided, however, a sample that represented regional differences in herd size and cropping characteristics (Jackson-Smith et al., 2000). Most (80%) Wisconsin dairy farms milk less than 100 cows, with average herd sizes between 70 and 80 cows. The highest percentages of farms having greater than 100 cows were found in the NE and SC regions. Farms operated on average between 115 and 125 ha farm^{-1}. All study farms ($n = 33$) grew alfalfa, and most (90%) grew corn. Soybeans and small grains were cultivated on 15 to 20% of all surveyed farms (mostly in the NE and SC parts of the state). Pasture is more important in the hilly SW than in other regions of the state.

Nutrient Management Behavior

Manure Management

When, where and how much manure was land-spread was estimated from approximately 16 100 manure spreader trips. Of the total trips made to fields in the NE (5582), the SC (6627) and SW (3878) regions, 70, 74, and 65% were made to corn fields; 7, 7, and 12% to new alfalfa fields; 11, 13, and 21% to established alfalfa fields; and 9, 3, and 2% to soybean fields, respectively. Of total manure trips in the NE and SC regions, only 2%

were to small grain fields and no manure was spread on small grain fields in the SW region. On the 33 farms, manure was applied to corn (1355 ha), established alfalfa (1270 ha), newly established alfalfa (330 ha), soybeans (285 ha), small grains (175 ha), and a few miscellaneous crops.

There were distinct regional differences in field sizes, distances between barns and fields, and seasonal manure land spreading practices (Table 2). Average field sizes where manure was spread were similar in the NE and SC (4.8 and 4.2 ha), which were about twice as large ($P < 0.05$) as in the SW (2.0 ha). There were significant ($P < 0.05$) regional differences in average "straight-line" distances between barns and fields that received manure: 1.01 km in the relatively flat NE, 0.70 km in undulating SC and 0.57 km in the hilly SW region of the state. In the SC and SW regions, fields that received manure were closer ($P < 0.05$) to barns than fields that did not receive manure. Also, there were distinct regional differences in the timing of manure applications. In the NE, most (42%) trips with manure spreaders were made during the fall and the least (10%) number of trips were made during the winter months. Higher fall than other seasonal applications were likely associated with soil conditions. The heavy-textured soils in NE Wisconsin are generally wet during spring, thereby limiting the number of manure spreading days during this season of the year (McCrory et al., 2004). In the SC region, most (37%) trips with manure spreaders were made during the summer and least (15%) during the fall. In the SW, manure spreader trips were distributed evenly throughout the year.

Manure Chemical Characteristics

The chemical characteristics of the semisolid and liquid manure spread on study farms are summarized in Table 3. There were few monthly differences in the chemical characteristics of semisolid manure. Concentrations of OM were generally higher during the period January–May than other months; concentrations of N were highest during the spring (March–May) and fall (September–November); and concentrations of P were higher in July–November than January–March. Chemical characteristics of liquid manure were similar during all stages of manure removal from pit storage, indicating that farmers successfully mixed manure pit depths before manure removal and land-application. On a wet weight basis, semisolid manure contained higher ($P < 0.05$) concentrations of OM, N and P than liquid manure, indicating that nutrients would be less expensive to spread as semisolid manure than liquid dairy manure (i.e., less watery).

Table 3. Manure characteristics on the 33 study dairy farms in Wisconsin.

Manure type	Sampling period	Samples	OM	N	P
			Chemical characteristics		
			g kg wet^{-1}		
Semisolid	Jan.	33	757ab†	4.43c	0.87cd
	Mar.	43	781a	5.18a	0.78d
	May	45	734abc	5.13b	0.90bcd
	July	44	665c	4.63bc	1.05a
	Sept.	47	672c	4.76abc	1.05ab
	Nov.	36	700bc	4.87abc	0.96abc
	mean	247	716 A‡	4.85 A	0.94 A
Liquid	pit full	40	721	3.62	0.61
	one-half empty	9	674	3.22	0.53
	one-third empty	27	700	3.75	0.62
	two-thirds empty	27	691	4.10	0.69
	almost empty	34	650	3.92	0.73
	mean	137	690 B	3.79 B	0.65 B

† Within a manure type, chemical characteristic means followed by different lowercase letters are significantly ($P < 0.0001$) different.
‡ Between manure types, chemical characteristic means followed different uppercase letters are significantly ($P < 0.0001$) different.

Nitrogen Applications to Corn

Available N applications to cornfields varied from 0 to 672 kg ha^{-1} across the state (data not shown), and averaged 185, 118, and 200 kg ha^{-1} in the NE, SC, and SW regions, respectively (Table 4). The relative contributions of fertilizer (40%), manure (30%) and previous legume (30%) to the total available N pool were similar across all three regions of the state. On single farms in each of the NE and SC regions, 5 and 6% of the total corn land (ha) received no N. Somewhat surprising were the 8 of 12 farms in the NE, 6 of 12 farms in the SC and 5 of 9 farms in the SW that had on average 38, 51, and 34% of their total corn land (ha), respectively in the low

Table 2. Field sizes, distances from barns, and seasonal manure spreading practices on 33 dairy farms in the Northeast (NE), South–Central (SC) and Southwest (SW) regions of Wisconsin.

Parameter (measurement)	NE	SC	SW
	Regions		
Farms (n)	12	12	9
Fields manured (n)	136	154	190
Manure field size (ha)	4.8a† (4.3–5.4)‡	4.2a (3.4–4.9)	2.0b (1.6–2.4)
Field distances (km from barn)¶			
Manured fields	1.01aA§ (0.87–1.17)	0.70 bB (0.63–0.77)	0.57 cB (0.52–0.62)
Nonmanured fields	1.27 aA (1.09–1.44)	0.91 bA (0.75–1.06)	1.07 bA (0.93–1.21)
Manure spreader trips (no. field^{-1})	29 a (24–34)	32 a (26–37)	15 b (13–16)
Manure spreader trip frequency (% trips)			
Fall (Oct.–Nov.)	42 aA (34–49)	15 cC (10–20)	28 bA (22–33)
Winter (Dec.–Mar.)	10 bC (6–15)	27 aB (21–33)	25 aA (19–30)
Spring (Apr.–May)	24 aB (18–30)	21 aB (16–30)	25 aA (20–31)
Summer (June–Sept.)	24 bB (17–31)	37 aA (30–44)	22 bA (17–28)

† Means across a row followed by a different lower case letter are significantly ($P < 0.05$) different.
‡ 95% Confidence intervals in parentheses.
¶ Straight line distance from barn to field center.
§ Column means within a parameter followed by a different upper case letter are significantly ($P < 0.05$) different.

Table 4. Available N applications to corn on 33 dairy farms in the Northeast (NE), South–Central (SC) and Southwest (SW) regions of Wisconsin (Oct. 2003–Sept. 2004).

Parameter	Measurement	Region NE	SC	SW
Operational				
	farms (*n*)	12	12	9
	fields (*n*)	108	116	132
	total corn area (ha)	504	576	180
Rates of available N applied to cropland (kg ha^{-1})	field average	185a† (161–210)	118b (103–132)	200a (180–222)
	application category	% total corn area		
	0	5 (1)‡ (–)	6 (1) (–)	0 (0) (–)
	1–80	38 (8) (24–51)	51 (6) (30–71)	34 (5) (5–62)
	81–160	37 (10) (26–47)	41 (12) (27–55)	36 (7) (18–55)
	161–240	32 (8) (16–48)	24 (10) (10–38)	25 (7) (9–41)
	>240	40 (6) (29–51)	31 (5) (7–54)	34 (6) (1–67)
Source of available N (%)	legume credits	30 (25–35)	28 (22–35)	36 (31–42)
	manure	28 (23–34)	33 (26–40)	26 (20–31)
	fertilizer	42 (35–48)	39 (32–45)	38 (32–43)

† Means across a row followed by a different letter are significantly ($P < 0.05$) different, 95% Confidence intervals in parentheses.
‡ Mean, number in parentheses are farms having cropland within application category; 95% Confidence intervals in parentheses.

available N application category (1–80 kg ha^{-1}). The large majority of farms (9–10 of 12 in the NE, 10–12 of 12 in the SC, and 7 of 9 in the SW) had their highest percentages of corn land in the 81 to 240 kg available N ha^{-1} category, the range that would encompass agronomic N recommendations for corn. Available N applications in excess of 240 kg ha^{-1} occurred on 6 of 12 farms in the NE comprising 40% of the corn area on those farms; on 5 of 12 farms in the SC, comprising 31% of the corn area on those farms; and on 6 of 9 farms in the SW, comprising 34% of the total corn area on those farms. On a regional basis, the following percentages of the total surveyed corn area fell within available N application categories of 0, 1 to 80, 81 to 160, 161 to 240 and >240 kg ha^{-1}, respectively: in the NE, <1, 26, 33, 21, and 19% of the surveyed corn area (504 ha); in the SC, <1, 39, 41, 14, and 5% of the corn area (576 ha); and in the SW, 0, 31, 45, 14, and 10% of the corn area (180 ha).

Phosphorus Applications to Cropland

The amount and source of P applications were tracked in 1070 fields comprising approximately 3050 ha (Table 5). In all regions, average annual available P applications were similar, a rate range of 22 to 27 kg ha^{-1}, of which approximately 65% came from manure and 35% from fertilizer. There were significant ($P < 0.05$) regional differences in available P application rates. Farms in the NE and the SC regions applied no P on 31 and 25% of their total cropland area, respectively, compared to 50% of the land area in the SW region. Most of the total surveyed cropland area received available P applications within range of 1- or 2-yr crop P replacement levels. There were 5 of 12 farms in the NE, 7 of 12 farms in the SC, and 6 of 9 farms in the SW that had on average 7, 15, and 4% of their total cropland (ha) in the 49 to 72 kg ha^{-1} available P application category, a category that would encompass the 3-yr crop P replacement level. Annual available P applications in excess of 72 kg ha^{-1} (an application rate greater than 3-yr crop P replacement) occurred on 2 of 12 farms in the NE comprising 13% of the cropland area on those farms; on 4 of 12 farms in the SC comprising 4% of the cropland area on those farms; and on 5 of 9 farms in the SW comprising 5% of the cropland area on those farms. On a regional basis, the following percentages of total surveyed cropland fell within available P application categories of 0, 1 to 24, 25 to 48, 49 to 72 and >72 kg ha^{-1}, respectively: 30, 50, 15, 4, and 1% of the cropland area (1340 ha) in the NE; 23, 54, 17, 5, and 1% of the cropland

Table 5. Available P applications to cropland on 33 dairy farms in the Northeast (NE), South–Central (SC) and Southwest (SW) regions of Wisconsin (Oct. 03–Sept. 04).

Parameter	Measurement	Region NE	SC	SW
Operational	farms (*n*)	12	12	9
	fields (*n*)	293	289	488
	total cropland area (ha)	1340	1168	542
Rates of available P applied to cropland (kg ha^{-1})	field average	22 (19–26)†	24 (19–26)	27 (19–26)
	application category	% of total cropland area		
	0	31b (12)‡ (22–40)	25b (12) (17–34)	50a (9) (35–65)
	1–24	44 (12) (34–55)	49 (12) (36–61)	41 (7) (25–56)
	25–48	19 (12) (11–27)	19 (11) (6–31)	13 (8) (7–18)
	49–72	7b (5) (1–14)	15a (7) (5–25)	4b (6) (1–6)
	>72	13 (2) (−76–103)	4 (4) (−2–11)	5 (5) (−6–22)
Source of total P applications (%)	manure	60 (54–66)	61 (55–65)	67 (62–73)
	fertilizer	40 (34–46)	39 (33–45)	33 (27–38)

† 95% Confidence intervals in parentheses.
‡ Means across a row followed by a different lower case letter are significantly ($P < 0.05$) different; number in parentheses are farms having cropland within application category; 95% Confidence intervals in parentheses.

area (1168 ha) in the SC; and 41, 48, 8, 1, and 2% of the cropland area (542 ha) in the SW.

Winter Manure Spreading in Surface Water Quality Management Areas

On average, most (80–91%) cropland area operated on the 33 dairy farms was not situated within surface water quality management areas (SWQMAs, Table 6). Some farms in each region, however, had one-third to one-half of their total operated cropland areas within SWQMAs. Of total (16100) annual trips made with manure spreaders, approximately 20% occurred during winter (Table 2). Of the total cropland area (484 ha) covered by winter manure spreader trips across all regions, approximately 17% was within SWQMAs.

In the NE, 100% of the winter-spread cropland area received available P application rates of 1 to 24 kg ha^{-1} (Table 7), the application range that would encompass 1-yr crop P replacement, which is the maximum allowable application rate according to nutrient management standards (DATCP, 2006). A statistically similar proportion (83%) of winter-spread cropland area was within this 1-yr crop P replacement application category for the SC region. The proportion (63%) of winter-spread cropland area in the SW that fell within the 1-yr available P application category was significantly lower ($P < 0.05$) than the NE region of the state. On a regional basis, the following percentages of total winter-spread cropland areas fell within available P application categories of 1 to 24, 25 to 48, 49 to 72 and >72 kg ha^{-1}, respectively: in the SC region, 78, 18, 2, and 2% of winter-spread cropland; and in the SW region, 64, 12, 12, and 12% of winter-spread cropland area.

DISCUSSION

Manure Spreading and Distance to Fields

As dairy farms expand herd size in response to rapidly changing market conditions (LaDue et al., 2003), access to close-by or contiguous fields for manure application often becomes increasingly difficult. Manure spreading on distant fields is time and energy consuming, and hence often not an economically viable option for the many Wisconsin farmers who rely on family labor for manure management. Previous studies (Shepard, 2000 and 2005; Nowak et al., 1997) concluded that Wisconsin dairy farmers apply manure more often to fields that are close to barns than to distant fields. Results from the present study found this to be the case only on farms situated in SC and SW, but not in NE Wisconsin (Table 2). Although overall distances between barns and fields were greater in the NE than in the SC and SW regions (Table 2), in the NE there was no difference in distances from barns to manured and nonmanured fields.

Regional differences in field distances that received or did not receive manure were somewhat surprising. Previous evidence suggested that farms in the NE were more likely than farms in other regions of Wisconsin to be renting fields that are more distant from barns and more difficult to access without transporting manure on heavily traveled commuter roads (Saam et al., 2005). It was thought that this could create disincentives for farmers in the NE to spread on more distant, rented cropland, compared to other regions having lower development pressure. In areas where farmers lack access to close-by fields for manure application, policy may be able to create incentives that promote closer spatial and operational linkages between crops and livestock. For example, manure contracts between crop and dairy producers can reduce hauling distances of manure. Such areawide integration can be the most energy and nutrient efficient form of crop and livestock production (Steinfeld, 1998).

Nutrient Management Practices vs. Recommendations and Regulations

Although most farmers blend fertilizer, manure and legume N credits, approximately one-half of the farmers in the NE and SC regions and two-thirds of the farmers in the SW region apply N in excess of corn requirements on 30 to 40% of their corn land. For P, relatively few farms would have to change current practices to adhere to the proposed Wisconsin Code 590 Nutrient Management Standard (DATCP, 2006).

The SWQMAs occupied only a relatively small portion (10%) of the total operated cropland area on the study farms, and most farmers avoided these areas when applying manure during the winter months. Manure spreading on frozen SWQMAs may be actually less than calculated. This study designated December through March as the winter period, a period when there would likely be periods of unfrozen soils and manure could be legally applied. Some farms, however, especially in the SC region, have large cropland areas within SWQMA,

Table 6. Cropland, Surface Water Quality Management Areas (SWQMA), and farmer manure spreading behavior on 33 dairy farms in Northeast (NE), South–Central (SC) and Southwest (SW) Wisconsin.

Parameter	Measurement	Region NE	SC	SW
Operational	**farms (n)**	**12**	**12**	**9**
	total cropland area (ha)	**1340**	**1168**	**542**
Cropland not within SWQMAs	**% total cropland farm^{-1}**	**88† (81–96)**	**80 (73–88)**	**91 (80–102)**
cropland within SWQMAs	**% total cropland area farm^{-1}**	**12 (4–19)**	**20 (12–27)**	**9 (−2–20)**
	% total cropland area in 91-m stream buffer	**1 (0–3)**	**7 (1–13)**	**7 (−7–29)**
	% total cropland area in 304-m lake/pond buffer	**11 (4–19)**	**13 (3–23)**	**2 (−4–11)**
Winter-spread manure in SWQMAs	**% total winter-spread cropland not in buffers**	**93 (83–102)**	**75 (58–90)**	**82 (59–104)**
	% total winter-spread cropland within buffers	**7 (−2–17)**	**25 (10–41)**	**18 (4–41)**

† Mean, 95% confidence intervals in parentheses.

Table 7. Manure P applications during winter on 33 dairy farms in the Northeast (NE), South–Central (SC), and Southwest (SW) regions of Wisconsin.

		Manured cropland		Manure P application category			
Zone	Farms	All year	Winter	1–24	25–48	49–72	>72
	n	ha		% winter manured cropland area			
NE	12	655	159	100a (12)†	0	0	0
SC	12	650	248	83ab (10) (73–94)‡	38 (9) (13–62)	9 (1) (–)	18 (1) (–)
SW	9	380	74	63b (6) (16–111)	50 (5) (−3–103)	35 (3) (−50–118)	33 (2) (−300–365)

† Means down a column followed by a different letter are significantly ($P < 0.05$) different; number in parentheses are farms having cropland within designated application category.
‡ 95% confidence intervals in parentheses.

and the management of these areas would require particular attention. The final set of farmer interviews to discuss individual farms' results revealed that many farmers who winter-spread manure in SWQMAs would be willing and able to change the timing and location of manure application to adhere to regulations.

Nutrient Management Practices and Structural Characteristics of Farms

The overall results of this study concurred with others (e.g., Nowak and Cabot, 2004; Shepard, 2005) that a relatively small proportion of Wisconsin dairy farms employ nutrient management practices that may be detrimental to water quality. Little information exists, however, on the characteristics of farms that tend to apply nutrients at recommended levels versus those that tend to apply nutrients excessively. The current regulatory focus is on large Confined Animal Feeding Operations (CAFOs), under the assumption that the relatively large amounts of manure they produce create a greater environmental risk than smaller farms that produce lesser amounts of manure. Also, having adequate cropland is a prerequisite to proper nutrient management. For example, Wisconsin dairy farms with stocking densities of 0.70 animal units (1 animal unit = 454 kg liveweight) ha^{-1} have sufficient cropland to spread manure according to a P-based nutrient management standard (Powell et al., 2002). For the 33 farms in this study, no differences were found in herd size (animal units $farm^{-1}$), cropland area (ha $farm^{-1}$), livestock density (animal units ha^{-1}) or manure collection (%) among farms that applied nutrients within and those that applied nutrients above recommended application rates (Table 8). Farmers who applied P in excess of agronomic recommendations, or applied manure during winter in excess of the 1-yr crop P replacement level, tended ($P < 0.15$) to apply manure to fields that were on average closer to barns than farmers that were following P recommendations. Overall, data from Table 8 indicate that farmer application of nutrients appears to be linked more to individual farmer behavior than to specific operational features of a farm.

Study Limitations

There were several possible errors associated with manure application records, including: (i) manure spreader was not always fully loaded, although farmer indicated it as "one load"; (ii) reliance on a single manure type per farm to estimate nutrient content of all manure applied, when in fact manure type varies between different age and production classes of the herd; (iii) unrepresentative or poorly handled manure samples; and (iv) manure not spread evenly across a field. Farmers noted in their manure logs the fullness of the spreader on embarking for manure land-spreading, but evidence suggested that a spreader that was only three-fourths full would still be marked as "one load". In such cases, nutrient application rates from manure would have been overestimated. During the initial and final farmer interviews, farmers reported that when a field is designated to receive manure, the whole field receives it. This assumption would lead to underestimation of application rates in those cases where manure was actually spread on only part of a field.

Table 8. Characteristics of 33 Wisconsin dairy farms that apply N and P at agronomic and excessive rates.

	Nutrient application type					
	Total available N		Total available P		Winter manure P	
	Nutrient application levels (kg ha^{-1})					
Characteristic	≤240†	>240‡	≤72†	>72‡	≤24†	>24‡
Farms (*n*)	16	17	22	11	18	15
Herd size (AU $farm^{-1}$)	125¶ (24–328)	125 (35–391)	139 (36–391)	95 (24–177)	137 (59–391)	108 (24–328)
Cropland area (ha $farm^{-1}$)	103 (15–267)	82 (30–270)	96 (30–270)	82 (15–250)	96 (30–270)	88 (15–250)
Livestock density (AU ha^{-1})	1.43 (0.70–2.07)	1.65 (0.73–3.64)	1.54 (0.70–3.13)	1.57 (0.73–3.64)	1.60 (0.70–3.31)	1.49 (0.73–3.64)
Manure collection (%)	68 (36–100)	62 (30–98)	66 (30–100)	64 (40–100)	65 (30–98)	66 (40–100)
	Field distance from barn (m)					
Nonmanured	910 (298–2404)	974 (193–2088)	965 (193–2404)	877 (402–2088)	1014 (193–2404)	829 (298–2088)
Manured	786 (279–1790)	650 (388–1228)	797a§ (402–2088)	566b (388–1022)	806a (279–1790)	612b (388–1022)

† ≤240, ≤72, ≤24 kg ha^{-1} denote nutrient applications within or below recommended rates. Farms (*n*) within these application rates have no fields that received nutrients above recommended application rates.
‡ >240, >72, and >24 kg ha^{-1} denote excessive nutrient applications.
¶ Mean (range).
§ Within a nutrient application type and nutrient application level, row means followed by different letter differ at $P < 0.15$.

As part of an overall validation of survey data, previous analyses (Powell et al., 2006) posed the question: how well did farmer-recorded data on their manure spreading practices reflect literature values of manure N and P excretions and losses, and other literature estimates of manure collection and spreading on a whole-farm basis? The sums (kg farm^{-1}) of field manure N and P applications recorded by farmers were compared to: (i) calculated manure N and P excretions by lactating and dry cows and heifers on each farm, and (ii) farmer estimates of apparent manure collection determined from data collected during the first interview. In brief, apparent manure collection was an estimate of potential manure available for land application, calculated as the difference in total manure excreted by the dairy herd and the amount of uncollected manure during periods of the year when lactating cows, dry cows and heifers were kept outdoors and manure went uncollected (Powell et al., 2005). The conclusion from this data validation analysis was that the sum (kg farm^{-1}) of field manure N and P applications recorded by farmers corresponded well to herd manure N and P excretions and associated losses, and to previous estimates of apparent manure N and P collection. This validation analysis provided confidence that farmer-collected data (e.g., data used to construct Tables 4 and 5) provided an accurate "snap-shot" of overall farmer manure collection and land-spreading practices on a whole-farm basis. Improvements would require increased skills and training of both farmers and those responsible for assisting farmers in data collection and analyses. Studies that rely on farmers filling out daily manure-spreading logs would be most effective when consistent contact is kept with the farmers, including fielding questions, addressing concerns, and encouraging ongoing farmer participation.

CONCLUSIONS

This study provided a general "snap-shot" of statewide and regional differences in nutrient management practices on Wisconsin dairy farms. Many farmers apparently integrated fertilizer–manure–legume–N management. Excessive N was applied, however, on approximately 30 to 40% of the corn land area situated on one-half of farms in the NE and SC regions, and on two-thirds of the farms in the SW region. Undesirable P applications occurred on relatively few farms, and were confined to relatively small cropland areas. Only few farmers applied P at rates that would have exceeded 3-yr crop rotation requirements. All farmers in the NE adhered to winter manure P spreading regulations. In the SC region, however, most farms winter-spread manure within protected surface water buffers (SWQMAs) at levels in excess of the regulated 1-yr crop replacement level. Whereas this 1-yr "snap-shot" of P applications revealed relatively good fertilizer and P management, year-after-year P applications to the same fields in excess of crop P requirement would certainly heighten the risk of P runoff and water quality impairment. Regional differences in nutrient management behavior due to topography, soils and other factors should be considered when devising statewide strategies aimed at improving fertilizer–manure–legume management on Wisconsin dairy farms.

ACKNOWLEDGMENTS

Partial funding for this research was received from USDA-CSREES Initiative for Future Agricultural and Food Systems, Grant 00-52103-9658 and NRI Agricultural Systems Program, Grant 01-35108-10698.

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